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Development and Research of a Current Source for Electrical Impedance Tomography

Aleksanyan G.K., Gorbatenko N.I., Kucher A.I., Shcherbakov I. D., Katsupeev A.A

Abstract: The probe current source is an essential component of equipment in electrical impedance tomography (EIT). This article discusses the development of a current source for an EIT - from a block diagram to a hardware implementation. A methodology for determining the output resistance of a current source is described, an experimental bench and the results of an experimental evaluation of the source output resistance - the most important parameter of current sources determining its characteristics - are presented.

Keywords : electrical impedance tomography; current source; output resistance; experiment.

I. INTRODUCTION

Electrical impedance tomography (EIT) is a promising method of medical imaging that allows reconstructing and visualizing the conductivity field Ω(x, y) inside the biological object (BO) (or the field of change in conductivity ΔΩ(x, y)) based on electrical measurements on the surface of a BO, when probing it with an electric current I of a high frequency [1-2]. The probe current source CS is the most important component of the EIT equipment, which determines the metrological characteristics of the entire measuring path [3,4]. Based on the analysis of the literature, the developed source must satisfy the following requirements:

- voltage control;
- the amplitude of the current through the load: 5 mA [5];
- error of current amplitude - not more than 1.5%;
- maximum current frequency - 100 kHz;
- grounded load resistance R_L 50 Ohm - 2 kOhm [6].

The use of inverting or electromechanical amplifiers with a load in the feedback circuit is impossible due to the fact that a constant potential cannot be applied to either end of the load, because in this case, one output or inverting input of the op-amp will be shorted [7].

The use of a current source according to the Howland circuit [8] is complicated by the need for very accurate selection of resistors to ensure a high output resistance CS.

The authors chose a CS circuit with automatic measurement and regulation of the current in the load [7,9].

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* Correspondence Author
Aleksanyan G.K.*, department of Information and measuring systems and technologies, Platov South-Russian State Polytechnic University (NPI), Russian Federation. Email:: graer@yandex.ru
Gorbatenko N.I., Professor, Head of Information and measuring systems and technologies department of Platov, South-Russian State Polytechnic University (NPI) , Russian Federation.
Kucher A.I., Associate Professor, Information and measuring systems and technologies department of Platov, South-Russian State Polytechnic University (NPI) , Russian Federation.
Shcherbakov I. D., Associate Professor, Information and measuring systems and technologies department of Platov South-Russian State Polytechnic University (NPI) , Russian Federation.
Katsupeev A.A., Associate Professor, Information and measuring systems and technologies department of Platov South-Russian State Polytechnic University (NPI) , Russian Federation.

II. MATERIALS AND METHODS

A. Development of a current source

The functional diagram of the developed CS as part of the data acquisition and transmission device for EIT is presented in Figure 1.

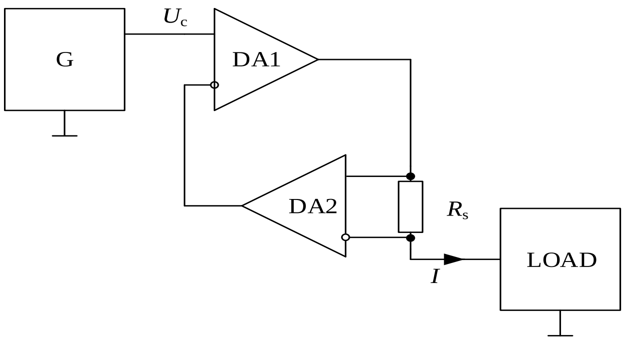


Fig. 1.Functional diagram of the current source

The output current is measured by the voltage drop U_S on the resistor R_S. For this, a differential amplifier on DA2 is used. If the gain K_U of the differential amplifier on DA2 is 1, then the output voltage of the differential amplifier DA1 is set such that the voltage drop U_S on the resistor R_S is equal to the input voltage U_c. Increasing the gain K_U allows to proportionally reduce the nominal resistance of the resistor R_S. To reduce the influence of the differential amplifier DA2 on the R_S shunt, it is necessary to provide the highest possible input resistance of the differential amplifier DA2 [10]. For this, for example, a tool amplifier or repeaters on OA operational amplifiers can be used. As DA1, the authors used OA AD8510ARZ manufactured by Analog Devices, as DA2 - the instrument amplifier AD8429ARZ produced by Analog Devices with an unconnected resistor R_G that sets the gain, which allows to provide the gain of the instrument amplifier equal to 1. Thus, 3 elements are used for implementing CS - two amplifier and current-carrying resistors R_s.

Schematic diagram of the developed probe current source CS is presented in Figure 2.

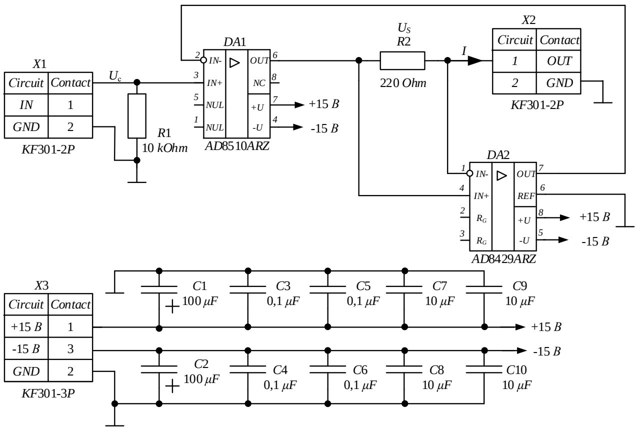
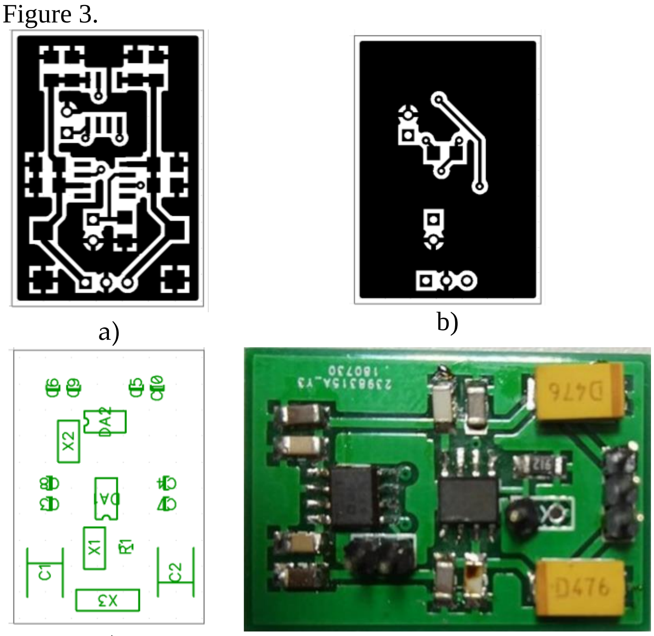


Fig. 2.Schematic diagram of the current source

The shape and frequency f_I of the current I at the terminal OUT of the current source correspond to the shape and frequency of the control signal U_c at the terminal IN of the current source. The amplitude Im of the current I at the output CS is proportional to the amplitude Um of the control voltage Uc at the terminal CS IN and is set by the resistor R2. The current source starts working immediately after the appearance of power on connector X3. The CS IN terminal is connected to a common point through a resistor R1 to avoid the occurrence of a current I to avoid the occurrence of a current I on the CS OUT terminal due to the induced voltage applied to the CS IN terminal.

The development of the CS circuit board was done using CAD DipTrace. The size of the board is 33.3 x 23.3 mm. The printed circuit board, assembly drawing, and the appearance of the assembled probing current source CS are shown in Figure 3.



a) b) c) d)

Fig. 3.Upper (a) and lower (b) layers of the printed circuit board, assembly drawing (c) and appearance (d) of the CS

B. Methodology for assessing the output resistance

One of the most important parameters of the current source, which determines its main characteristics, is its output resistance R_{OUT} [11]. As you know, an ideal current source has an infinitely large output impedance R_{OUT}. A real current source has a final R_{OUT}, connected in parallel with the load resistance R_L (Fig. 4).

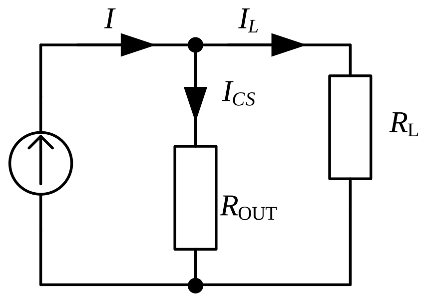


Fig. 4.Equivalent current source circuit taking into consideration output resistance

As a result of the fact that Rout is finite, ICS current will flow through it. Thus, the total current IL through the load RL will be less than the output current I of the current source by the amount of current ICS. Obviously, for the circuit in Fig. 4, condition (1) is satisfied:

$$\frac{I_{CS}}{I_L} = \frac{R_L}{R_{OUT}} \quad (1)$$

Thus, so that the influence of the output resistance R_{OUT} on the current I_L through the load R_L does not exceed 1%, the value of R_{OUT} must satisfy the condition $R_{OUT} \geq 100\ R_{Lmax}$. The value of R_{Lmax} for the developed circuit is determined by the value of the current-carrying resistance R_S and the maximum resistance by which the output of OS1 can be loaded. For OA AD8510ARZ with a supply voltage of V_{DD}=+15 V and V_{SS}=-15 V, the maximum output voltage is at least ±14 V. In order to provide an output OA current of at least I_{OA}=±5 mA at an output voltage of ±14 V, the value of the resistance R_{OAO} applied to the OA output must not exceed 2600 Ohms. Since $R_{OAO}=R_S+R_L+R_M$ (where R_M is the resistance of the current injection channel, which is determined by the resistance of the multiplexers). For the used DG406 multiplexers, the open channel resistance does not exceed 100 Ohms, and the typical value is 50 Ohms. Thus, R_{Lmax}=2180 Ohms.

Output resistance R_{OUT} cannot be measured directly. But there are indirect ways to measure R_{OUT}. Knowing the given current level I, as well as the current value I_L through the load resistance R_L for the maximum and minimum values of the load resistance R_H, we can calculate the value of the output resistance CS R_{OUT} according to the formula (2):

$$R_{OUT} = \frac{I_{L2} \cdot R_{L2} - I_{L1} \cdot R_{L1}}{I_{L2} - I_{L1}}, \quad (2)$$

where I_{L1} – the amplitude of the current through R_L at R_L= R_{L1}; I_{L2} – the amplitude of the current through R_L at R_L= R_{L2}.

C. Experimental bench

For an experimental evaluation of the output resistance R_{OUT} CS, we measure the amplitude of the current R_L at the maximum and minimum value of the load resistance R_L. As the load R_L, resistance with the nominal value of R_{L1}=52 Ohm and R_{L2}=2155 Ohm is used.

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The experiment is conducted for control voltage frequencies f_{cont} =10;20;30;40;50;60;70;80;90;100 kHz and amplitude I_m = 5 mA. The number of repeated experiments is 11.

A universal voltmeter AKIP-2101 is used to measure the I_L current amplitude. To generate the control signal U_{cont}, a signal generator of a special form AKIP-3409/5 is used. The block diagram of the experimental bench is shown in Figure 5.

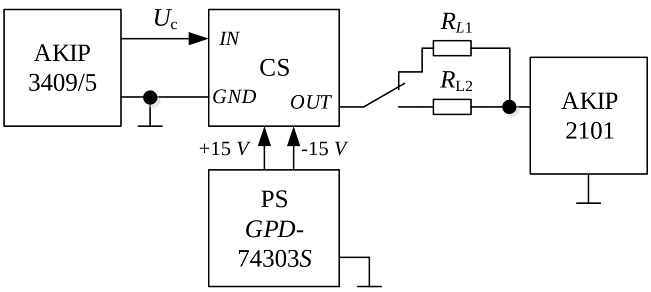

Fig. 5.Upper (a) and lower (b) layers of the printed circuit board, assembly drawing (c) and appearance (d) of the CS

III. RESULTS

Using the experimental bench (Fig. 5), the RMS values of the current through the load R_L were obtained. According to the data obtained, the amplitude values were restored. Then, using the formula (2), the values of the output resistance were calculated. The results are presented in Figure 6 in the form of a box plot to represent the median value of the output resistance, lower and upper quartiles, and emissions. The relative error of the current I through the load R_L from the change in the load resistance R_L was estimated using the formula (3):

$$\delta(f_I) = \frac{I_{max}(f_I) - I_{min}(f_I)}{I_{mean}(f_I)} \cdot 100\%;$$
$$I_{mean}(f_I) = \frac{I_{max}(f_I) + I_{min}(f_I)}{2}. \qquad (3)$$

where I_{max} – maximum current I through load R_L at frequency f_I; I_{min} – minimum current I through load R_L at frequency f_I.

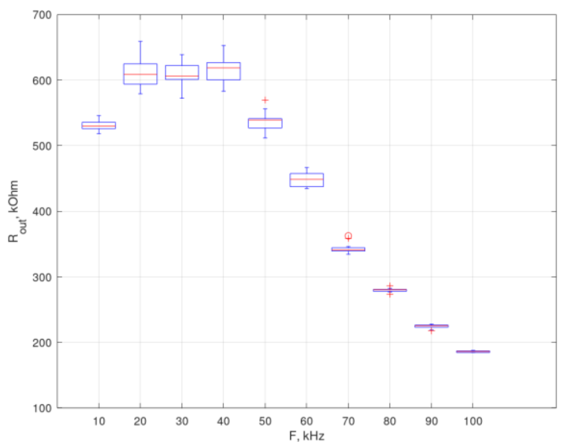

Fig. 6.Schematic diagram of the current source

The median, maximum and minimum values of the current source output resistance R_{OUT} and relative error of the current I through the load R_L are presented in table 1.

Table- I: R_{OUT} resistance rating results

F, kHz	R_{OUT}, kOhm			I
	Median	Max	Min	δ,%
10	529,97	546,03	518,50	0,43
20	608,89	659,33	579,31	0,39
30	606,43	639,00	572,42	0,38
40	618,82	652,98	583,27	0,38
50	539,30	569,78	511,89	0,43
60	448,74	466,70	434,75	0,51
70	341,05	362,56	334,45	0,64
80	280,22	286,14	273,51	0,78
90	225,55	227,88	217,54	0,97
100	186,10	187,71	184,54	1,15

As can be seen from Figure 6 and Table 1, in the frequency range f_I=10..100 kHz at a current amplitude of I_m = 5 mA, the output resistance of R_{out} CS is in the range from 659,33 to 184,54 kOhm. An analysis of the values of the current amplitude I_m through the load R_L in the frequency range f_I=10..100 kHz shows that at a constant frequency of the injected current f_I changes in the load resistance in the range from 50 kOhm to 2 kOhm lead to a change in the amplitude I_m of the current I by no more than 1.2 %. At the same time, a change in the frequency f_I of the injected current at a constant load R_L leads to a change in the amplitude I_m of the current I by 8.2%.

IV. CONCLUSION

The developed CS is voltage-controlled, allowing to provide current through the load R_L up to 5 mA. The change in the amplitude of the current I_m through the load R_L in a given range of changes in does not exceed 1.5%, however, with an increase in the frequency of the injected current f_I, the amplitude of the current I_m sinks by 8%. This parameter can be improved by using higher frequency OA. However, in this case it is necessary to pay great attention to the layout of the printed circuit board, as the probability of self-excitation of the circuit increases. At the same time, modern instrumentation amplifiers, most commonly, have a low frequency of the unity gain. In this case, it is necessary to use 3 high-speed OA, combined into a tool amplifier (one OA for implementing a differential amplifier, a pair of OA for implementing repeaters for each breath of a differential amplifier). The authors plan to further implement this scheme to minimize the influence of the frequency f_I of the injected current on the amplitude I_m of the current I.

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AUTHORS PROFILE

Aleksanyan G.K. Candidate of technical sciences, associate professor of Information and measuring systems and technologies department of Platov South-Russian State Polytechnic University (NPI), Russian Federation. Supervisor of agreement No. 05.607.21.0305

Gorbatenko N.I. Doctor of Technical Sciences, professor, Head of Information and measuring systems and technologies department of Platov South-Russian. Academician of the Academy of Medical and Technical Sciences of the Russian Federation, member of the Saxon Academy of Sciences (Germany). Honored Scientist of the Russian Federation

Kucher A.I. Candidate of technical sciences, associate professor of Information and measuring systems and technologies department of Platov South-Russian State Polytechnic University (NPI) , Russian Federation. The topic of the Ph.D. thesis is Method and system for monitoring human lung ventilation based on electric impedance tomography

Shcherbakov I. D. Master in Instrument Engineering, assistant of Information and measuring systems and technologies department of Platov South-Russian State Polytechnic University (NPI) , Russian Federation. Now working on the problems of electrical impedance tomography

Katsupeev A.A. Candidate of technical sciences, associate professor of Information and measuring systems and technologies department of Platov South-Russian State Polytechnic University (NPI) , Russian Federation. His main researches include electrical impedance tomography, computer science